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When calculations shall be based upon the best data obtainable as to the materials of the earth's interior and their arrangement therein, then, and not till then, will mathematical calculations have real weight that geologists are bound to respect, but that day is a far distant one.

In the mathematical discussion of the state of the earth's interior, it has been customary to select a homogeneous globe of uniform density, but when the earth has been assumed to be heterogeneous and of varying density, it has been regarded as composed of layers, the layers being of unequal density when compared with one another, but of equal density throughout their own mass.

The more probable condition is that of a globe with a gradual increasing density from the exterior towards the interior, but with the materials heterogeneously arranged in the so-called layers. While the heavier materials would increase in abundance and the lighter diminish as the interior was approached, and *vice versa*, these materials at any one point would be found to be mixed together in varying proportions, the same as they are in meteorites and terrestrial eruptive rocks. While the extremes of the series may, indeed, be free from one another's components, the intermediate layers would contain more or less of the materials that predominate in the other portions of the earth's interior.

(To be continued.)

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VESTIGES OF GLACIAL MAN IN MINNESOTA.

BY MISS FRANC E. BABBITT.

DURING the open winter of 1878–9 and the seasons immediately succeeding it, the writer of this paper chanced to be engaged in searching certain terrace surfaces of the Mississippi river for palæolithic remains supposed to exist at the locality under examination. Rudely worked quartzes had previously been discovered here by the State geologist of Minnesota, Professor N. H. Winchell, by whom they had subsequently been described and figured in the State geological report for 1878. The field of exploration lies in central Minnesota, about one hundred miles northwest of St. Paul, and within the township and small village of Little Falls, Morrison county. Its area is at present restricted to a narrow section of the Mississippi valley, stretching along the river a short distance from the central site of observation.

The find reported by Professor Winchell consists of chipped objects of a class generally ascribed to what is called the *rude stone age.* Of these, many appear to be mere refuse, while others are regarded as finished, and unfinished implements. The Winchell specimens have been assigned, upon geological grounds, to a prehistoric era altogether antedating that of the mound-building races, and reaching back to a time when the drift material of the terrace-plain was just receiving its final superficial deposit. It is found that, at intervals, the surface soil of the terrace is permeated with these quartzes to a depth of not unfrequently three or four feet.

The lowest and newest formation at this place constitutes the actual flood-plain of the river. It is still in process of development, is of fluctuating width and thickness, and is, at certain points, yet subject to partial overflow at periods of exceptionally high water. In that portion of the township of Little Falls situated east of the Mississippi, this bottom land is limited on the east by a higher ancient river terrace, which has, at the head of the rapid called Little Falls, an average elevation above the river of about twenty-five feet, with a width of a mile or more.

This older terrace, like the present flood-plain, is of undoubted *drift* origin, and has been spread out by the immediate action of water. Mr. Warren Upham, assistant on the State geological survey, tells us that it consists of stratified gravel and sand; that it forms a part of the modified drift, deposited at the close of the last glacial epoch of the great ice age, by the floods descending along this valley from the melting and retreating ice-sheet; and that it was derived from the drift material which had been contained in the lower portion of the ice. It belongs to the great system of river-terraces, extending from an indefinite beginning on the north, to the embouchure of the Mississippi on the south. Wherever from any cause the lower plain, or bottom-land, does not exist, the edge of the upper plain becomes, of course, the real bank of the river; at places where, on the other hand, the newer deposits appear in force, the ancient terrace-banks either abut directly upon them in a pronounced line of steeps, or descend to them by gentle slopes.

The upper terrace of the Mississippi valley is, at Little Falls, defined on the east by a broken chain of uplands which take on different names in different parts of their course. Thus they are known in Wisconsin as the *Kettle range*, and in Minnesota and Dakota, as the *Coteau des Prairies* and the *Coteau du Missouri*, respectively. Geological authorities agree that the range indicated is a series of terminal moraines, and that it defines the limits attained by the great northern glaciers, at the acme of their southern advance, during the last of the universally recognized glacial epochs of North America. The morainic belt is regarded as an accumulation of débris, due to long-continued glacial halts, and alternations of advance and recession; the rubbish thrown down by ice melting while stationary or creeping back, at one time, having been plowed up and redistributed at the next subsequent period of forward movement. When the climate at length became permanently warmer, and the glaciers withdrew for the last time to the frozen regions of the north, they left their outline traced, as in a scroll of huge hieroglyphics, across the open page of the continent.

This morainic belt does not follow the lines of latitude, but descends to its southern limit in an irregular series of broad and often very long lobes. These touch each other, and merge into one at their lateral borders, on the east and west, while at the southern terminus each preserves an independent outline, taking on a rounded contour at the extremity, and ending in a more or less elongated curve prolonged towards the south. Thus we have, in southern Wisconsin, the well defined moraine of a great glacier descending from Lake Michigan into northern Illinois, the western edge of which was joined by the eastern margin of a similar ice-current coming down from Green bay. The débris of their united edges moved forward along the midst of their combined masses in a single line of aggregation, now known as a *medial moraine*. At the extremity, each glacier descended independently to the south, where the moraines of both yet exist in the form of two large, irregularly rounded lobes, joined at the base of the medial moraine.

Still west of the Green Bay moraine lies that of the northeast glacier, the western edge of which is skirted, at Little Falls, by the terrace-plain of the Mississippi river, as hitherto described. A few miles further west still, on the opposite side of the Mississippi, yet another moraine of the modern epoch comes down from the northwest, but without impinging directly upon that from the direction of Lake Superior in the latitude of Little Falls, where the two are separated by an interval of several miles. As we are assured, however, by Mr. Warren Upham, the two finally come together in Stearns county, some little distance south of Morrison county. Geologically considered, then, the field of study lies in an ancient terrace-plain east of the Mississippi river, is situated precisely between the northeast and northwest moraines, and is, so far as the quartz stratum to be described is concerned, buried under an accumulation of modified drift deposited by glacial waters.

While occupied in examining the river bank in quest of wrought quartzes, one day during the season of 1879, I had occasion to ascend a slope lying between the new flood-plain and the older one, by a pathway leading through a sort of gap, or notch, in the latter. Henceforth I shall, for the purpose of more emphatic distinction, denominate the lower and higher levels under consideration as *bottom-land* and *terrace-plain*, respectively. It seemed that at some past period a cut had been effected here by drainage, and that the washout thus formed had afterward been deepened through being used as a wagon-track. In this notch I discovered the soil to be thickly strewn with pieces of sharp, opaque quartz. These were commonly of a white color, and ranged in size from minute fragments to bits as large as a man's hand, and in some instances even larger.

There were many hundreds of these chips visible, scattered over an area of the width of the wagon-track, and ten to fifteen yards in length. They were conspicuously unwaterworn and likewise, in the main, unweathered, though occasionally a bit was picked up having some one of its surfaces weathered, while fractured or wrought faces appearing upon other parts of it, looked as fresh as if the work of yesterday. On the other hand, the mass of stone rubbish upon and among which the quartzes were strewn, is much waterworn, many of the pieces being well rounded, while none of them are wholly angular.

Most of these quartz pieces had, when first observed, a sort of bleached exterior unlike that of the rusty-looking specimens subsequently exhumed from the stratum adjacent; but this was no doubt due to the complete superficial cleansing to which they had been subjected by recent exposure to the elements. At all events, the bleached appearance proved a merely temporary characteristic, for although the quartzes received a thorough washing up immediately after being collected, they directly began to take on anew a tawny yellowish tint which, within a few months, became decidedly pronounced. They were again carefully cleansed with brush and water, again to resume their rusty tone of color. In a few instances the process of brushing clean was repeated at intervals of four or five months, a third and even a fourth time, with similar results. The degree of discoloration appears to vary with the quality of the specimens affected, the most compact varieties of mineral undergoing the least modification of tint. The coloring also fluctuates, probably, with the fluctuating proportion of iron in the containing soil.

It was soon ascertained that the notch, and the surfaces immediately surrounding it, afford no boulders nor other supplies of quartz except these chips. Nor does quartz appear on the east shore within a radius of perhaps an eighth of a mile from the spot, although it occurs plentifully just north and south of these limits, both in the form of veins in the slate rock of the region, and in that of waterworn river-wash and occasional boulders. Waterworn lumps of quartz are now and then found, it is true, in the subjacent till, but the latter lies several feet lower than the quartz-bearing stratum, beneath which it directly penetrates, and hence could never have yielded the specified objects through natural processes. An additional fact, worthy of note, is the invariably small size of the pieces disclosed. But a single fragment larger than a club-head has, as yet, come to light anywhere at the notch, and that one was not imbedded in the undisturbed strata at the notch proper, but in the débris at its base and west of it. Even could there have existed at this site masses of mineral important enough to furnish the tens of thousands of chips and lumps with which the place has proved to be paved, it appears wholly incredible that such rocky masses could have been thus absolutely annihilated, except through human interference. The waterworn stone rubbish below the quartzes remain undisintegrated, therefore so we should expect the latter likewise to be found. There is no known reason why, having been subject to the same influences, the one should have been broken into small pieces, and even splintered into the tiniest bits, while the other escaped disintegrating forces.

In view of the circumstances cited, it was finally concluded that the quartzes must have been artificially transported to their actual position, perhaps in fragments, perhaps in masses which were afterward broken into fragments. For a period of about four years the quartzes were largely augmented in number at every succeeding freshet, during which they were washed out of the inhuming sand of the roadway by descending drainage. Their immense and continually increasing quantity finally seemed to warrant the belief that they had resulted from systematic operations of some sort, once conducted, for unknown purposes, upon that particular spot. A portion of the studied specimens subsequently yielded evidence of having received shape from human hands.

The theory of neolithic origin was, from the beginning, beset with embarrassments. Certain incongruous developments became increasingly perplexing with the advance of investigation. The spot appeared to be peculiarly unfitted by nature for a base of quartz-working operations. It was unintelligible, for example, why an important industry of this sort should have been established at so great a distance from quartz boulders and quartz-bearing rock, especially as convenient plains occur about the nearest exposures of this mineral. Again, why should such a manufactory have been set up upon a steep hill-side with its approaches of such a character that all the material to be handled, as also the implements fashioned, would have to be transported to and fro, up and down a considerable acclivity? Above all, why should this workshop have been relegated to the bottom of a natural drain, the solid contents of which were necessarily overwhelmed, or swept away bodily, at every considerable rainfall and thaw of the year? As an illustration of the superficial disturbance to which the place was subject, I may mention that at the close of a long but by no means exceptionally protracted rain-storm, I once collected from the notch, by actual count, about one thousand quartzes, all newly plowed out of the soil at that one time. Of this I was certain, as I had previously cleared the ground of every quartz piece of any size within view.

A final fact wholly irreconcilable with the hypothesis of neolithic origin, was the absence of quartzes from the surfaces at the superior edges of the notch, and along the terrace-plain adjoining. It was not for a moment to be believed that such remains would have been thus distributed by aboriginal artificers. It was simply impossible that the quartz-workers should have limited their manipulations to a strip of sand six or eight feet wide and thirty to forty long, less or more, heaping upon this narrow defile thousands upon thousands of fragments, yet leaving absolutely no small splinters nor chips beyond, neither up the slopes of the notch nor elsewhere in the vicinity.

The above-cited peculiarities of distribution remained the puzzle of the situation until certain of the accumulated objects began to range themselves under types which, though vaguely outlined in touches of extremely rude workmanship, were, nevertheless, distinctly palæolithic in general tone.

The quartzes were now, for the first time, conjecturally classified with the palæolithic implements discovered by Professor Winchell imbedded within the surface of the terrace-plain, and figured in his geological report of a reconnoissance in Morrison county. It was judged that, as had been the case with the Winchell specimens, these objects had been included, primarily, within an upper stratum of the terrace-plain, whence they might easily have been washed by the drainage water copiously discharged through the notch. Such pieces, it was argued, would naturally be stranded near their starting point, yet at a level somewhat below, while the finer enveloping sand associated with them would be carried on and deposited at a more distant spot. It is necessary to keep in view the distinction between *post-glacial* relics and the quartzes found by Professor Winchell. The discoverer holds these latter objects to be essentially a part of the drift of the last glacial epoch, and considers them to have been fashioned prior to the spreading out of the uppermost material of the plain in which they are, at various points, distributed. It goes without saying, that post-glacial remains, on the contrary, are or have been posed upon the face of the drift, and not within its mass. In searching the spot for Indian relics I had confined my attention principally to the surface of the ground; in setting up a quest for palæolithic objects of the class described by Professor Winchell, I examined vertical sections of the upper terrace-plain to a depth of several feet.

Prolonged investigation ensued, establishing the hitherto unsuspected fact that the notch quartzes could never have been directly involved in the terrace surfaces. Had they once been thus inhumed, the superficial stratum of adjacent drift would assuredly have been found to contain a greater or less proportion of similar fragments, scattered throughout its substance. But this was not the case. On the contrary, no buried quartzes whatever appeared in the superior exposures of the notch, nor within the horizontal surfaces at either hand, though such were sought with careful scrutiny. Since November, 1879, at which time the studies here recorded were in active progress, the wagon-track hitherto mentioned in this paper has been converted to public use as a highway, and has been repeatedly graded in consequence. As might be conjectured, the ground has been much dug over, the stratum being, at present, almost broken up and destroyed, if not wholly so. During three successive seasons, the road has been in a state of almost constant repair, owing to its being continually used for the heavy work of dragging logs from the bottom-land to the top of the terrace-plain. From this and other disturbing causes, not necessary here to specialize, the topography of the spot has been materially modified of late, while quartzes from the bed of the notch, as likewise from the stratum at first discovered, have been much mixed up with the surrounding soil. Primarily, however, as I permit myself to reiterate in the way of emphasis, I could not, with a great deal of painstaking, find any superficially inhumed quartz fragments at the point of observation; although, as shown by Professor Winchell, and as I have myself had abundant occasion to observe, such quartzes occur in the surface stratum of the terrace-plain at various isolated localities in the vicinity. So far as I have been able to judge, these appear in groups which are surrounded by considerable areas containing no observable remains. The absence of chips above a plane a foot or two superior to that of their bed at the bottom of the notch was, of course, a marked circumstance, since they should have occurred plentifully in the superficial stratum, had the notch chips been, as assumed, of the same age with Professor Winchell's find.

Ultimately it was ascertained that the notch quartzes had dropped to the level at which they were first seen, from a thin layer of them, once lying from ten inches to two feet above, and subsequently broken up through the eating out of the sand underneath by drainage, supplemented by the action of wagonwheels. This layer or stratum was still intact on the north and south, and partially so on the east, in which direction it had, however, at certain points suffered displacement by wagoning. It extended in what at the time appeared to be a nearly horizontal plane, into the terrace, in the sloping edge of which the notch, opening in the west bank of the terrace and truncated at its edge, is cut. Its outlines, lying within the walls of the notch, were masked against ordinary observation by thin slides of soil from higher surfaces. Both the inferior and superior planes of the quartz bearing stratum were sharply defined. Its horizontal boundaries had not been distinctly reached in any direction at the time of excavating for the road, and they have since been, at least partially, and perhaps wholly, obliterated by the grading and digging over to which the spot has been subjected. At the west the stratum reached to the limit of the terrace, which is here bounded by a steep slope. The quartz-bearing layer averaged a few inches only in thickness, varying a little as the included pieces happened to be of smaller or larger size. The contents were commonly closely compacted, so much so that one might sometimes extract hundreds of fragments, many of them very small ones, of course, from an area of considerably less than a square yard.

The quartz bed, as far as examined, rested upon a few inches of sandy soil which passed downward into a coarse stone rubbish immediately overlying till. Upon the quartzes again, were superimposed drift accumulations extending up to the surface of the terrace. These were characterized, by geological authority, as sand above and sand and gravel below. The pebbles of this gravel were small and well rounded, and were noticeably less angular than those of the rubbish beneath. The stratum of quartzes lay at a level twelve or fifteen feet lower than the plane of the terrace top. The exposed deposit has been found to dip toward the west, and apparently also toward the south ; but these inclinations, particularly the former, may be partially or wholly due to the giving way of underlying rubbish. At an early stage of investigation the soil above the quartzes presented to the eye no contrast in color with that of the soil below them. After penetrating some little distance, in a horizontal direction, into the terrace, however, the superior and inferior strata began to show a plain divergence in point of tint, the lower one taking on a dull yellowish red tinge. After a certain degree of exposure the differential color line fades out, perhaps through the washing into the edges of the excavation of foreign material. Still it has been found to be set up anew at every fresh cutting.

At present everything indicates that these Little Falls quartzes were originally posed upon an ancient surface, since covered by what the glacialists term *modified drift*, now forming all the upper part of the terrace-plain. It will be remembered that the quartz chips and implements discovered by Professor Winchell, in this vicinity, are contained only in the upper stratum of the terrace-plain. Now the notch quartzes do not at all appear at the terrace top, and cannot have been derived from it. They are, on the other hand, confined strictly to a single thin stratum of the lower gravels closely overlying till, and sometimes, perhaps, merging into it on the west, as hereafter explained. Hence the two sets of objects cannot be synchronals, though they may have been produced by the same race at different stages of its existence. The notch quartzes must of course be older than those of the superior stratum of drift by at least the lapse of time required for forming and draining the deposit lying between the quartzes below and those above.

Professor Chamberlin, State geologist of Wisconsin, in treating of the ancient vegetal deposits of his district, precisely indicates what at the present moment appears to be the glacial position of the Little Falls quartz stratum. Speaking of the Kettle moraine of Wisconsin, which is continuous with the northeast moraine of this region, he says:

> "Some of these organic strata lie at the immediate foot of the moraine beneath fluviatile and lacustrine deposits that, I am confident, began to be accumulated during the accumulation of the moraine and through the agency of glacial floods."

The observations recorded above are offered in their present form as a special answer to inquiries and suggestions propounded to the writer, from time to time, by archæological investigators. They are likewise adduced as evidence that the theory of an ancient quartz-paved surface is not the result of a mere hasty guess, but is, on the contrary, the slow outgrowth of many particular observations and deductions. Certain of these, however, remain yet to be stated. The facts above given will, it is hoped, plainly illustrate the successive steps by which the present working hypothesis has been reached. They are arranged to show:

First; why the notch quartzes are not attributed to natural causes now operating upon the present surface.

Second; why these objects are not ascribed to modern races once inhabiting the region.

Third; why they are not classed with the implements previously unearthed at Little Falls by Professor Winchell.

Fourth; why they are referred to a palæolithic people once inhabiting an ancient till surface, which is at present buried beneath a sheet of modified drift. Of this, however, more hereafter.

At present, palæolithic remains are assigned to three distinct eras:

The *preglacial*, or anteglacial, including geological time wholly preceding the ice epochs.

The *interglacial*, time between any two of these epochs.

The *intraglacial*, time during such an epoch.

According to the generalization of Geikie, adopted in this paper, *postglacial* relics, however rude they may be, are not truly palæolithic, although they may be popularly reckoned as such.

It is not possible that the notch quartzes belong to the first of these palæolithic classes. They cannot be preglacial because they are based upon till, a deposit which is universally acceded to be a ground moraine, formed, in some way, at the bottom of a glacier, and left behind when the glacier withdraws. In the present case the underlying till must not only have been laid down, but must likewise have been permanently uncovered by the recession of the producing ice, before the quartz-workers could at all have gained access to it, much less have set up their primitive industries upon its surface. These objects are furthermore clearly not postglacial, because they lie under a sheet of modified drift, fifteen feet and less in thickness, which has certainly been produced in one way or another by dissolving glaciers.

The question whether the quartz deposit is intraglacial or interglacial in origin is one which is not so readily answered in the present state of our knowledge. Indeed, it may very well be both perhaps; that is, it may have had a beginning prior to the final advance of the northeast and northwest glaciers, and then have continued to exist, and to receive accretions from time to time, up to a period during the second ice age when these glaciers were in process of final liquefaction. Certain elements of the geological situation recently developed by American scientists, and already touched upon in this paper, necessarily enter as essential factors into the solution of the problem before us. The following is a summarized recapitulation of glacial principles enunciated by authorities now engaged in deciphering the ice chronicles of the Northwest:

That this whole region has been subjected to a period or periods of glaciation antedating the last.

That a longer or shorter era of deglaciation, known to scientists as an interglacial epoch, intervened between the deposit of the older tills and the readvance of the northeast and northwest glaciers during the latest ice period.

That the general direction of glaciation was similar during the earlier and later ice epochs, though it was not always precisely the same.

That glaciation was far more extended in its range at the former of these periods than at the latter; the ice of the former having stretched fully three hundred miles south of the termini of the modern morainic lobes.

That the modern morainic belt defines the limit of extension of the glaciers during the last ice epoch.

Finally, that the Little Falls quartz stratum lies between the modern moraines of the northeast and northwest glaciers, in a medial morainic belt which is characterized by a system of overlapping tills, as described in Mr. Upham's paper at the close of this article.

The above elements sum up the glacial situation as understood by specialists, so far as concerns the quartz stratum under consideration. The tills of Morrison county have, up to the present time, not been fully reported upon, and their special interrelations are accordingly very imperfectly understood.

(To be continued.)

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THE GENESIS OF CRYSTALLINE ROCKS.[1]

BY T. STERRY HUNT, LL.D., F.R.S.

THE writer began by an account of the various hypotheses hitherto proposed to explain the origin of the ancient crystalline stratified rocks, of which gneiss may be taken as the type,

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[1] Abstract of a paper read before The National Academy of Sciences, April 15, 1884.